Brief Summary of ACE Aerosol-Related Studies and Activities

- PODEX[1]
  - Aerosol retrieval studies
  - Polarimeter comparisons[2]
- Additional aerosol data acquisition/retrieval studies
  - Passive[3,4,5] (e.g. RSP, AirMSPI in SEAC4RS)
  - Active[6] (e.g. HSRL-2 in DISCOVER-AQ)
- Swath Sampling Studies
- Multiwavelength lidar aerosol retrievals and satellite simulation[6,7]
- Radiative Forcing Studies
- Aerosol Indirect Effect Study
- Aerosol Type Constraints Required for Ocean Color Atmospheric Correction[8]
- Aerosol Data Assimilation[9]
- Aerosol measurements from current and potential future PACE mission as related to ACE science objectives[10]

Details in meeting presentations that follow:

[1,10]Ferrare, [2]Knobelspiesse, [3]Cairns, [4]Diner, [5]Martins, [6]Hostetler, Whiteman[7], Kahn[8], daSilva[9]

PODEX Retrieval Studies

- Polarimeter teams (AirMSPI, RSP, PACS) working on various methodologies for implementing aerosol retrievals
  - Individual teams investigating various radiative transfer codes including Generalized Retrieval of Aerosol and Surface Properties (GRASP) algorithm (Dubovik *et al, 2011*)
- PODEX analyses draw on coincident airborne in situ (LARGE group on P-3) and remote sensing (HSRL-2 on King Air, surface AERONET) data collected during DISCOVER-AQ for evaluating aerosol retrievals
- SEAC4RS provided additional datasets (AirMSPI, RSP) that enable additional polarimeter-related aerosol and cloud studies
- PODEX summary will discuss experiment, measurements, analyses (Ferrare)
- Polarimeter comparisons (Knobelspiesse)
  - Intensity, polarization studies
  - Investigations of calibration techniques

Aerosol studies for ACE

May 23, 2014

David J. Diner, Anthony Davis, Michael Garay,
Olga Kalashnikova, Feng Xu
(JPL)

Aerosol retrieval algorithm development

- JPL-developed RT code used as basis of aerosol retrieval algorithm, with support from Oleg Dubovik (Univ. of Lille)
- GRASP code developed by Oleg is being evaluated in parallel

	JPL code	GRASP
Forward RT calculation method	Markov Chain + Doubling/Adding	Successive Orders of Scattering
Aerosol particle size model	Multi-bin, bimodal	Multi-bin, multi-modal*
Particle shape	Spherical	Spherical, spheroidal
Refractive index	Mode dependent	Mode independent
Land surface model	Modified RPV + Fresnel microfacet distribution	RPV + Maignan model
Ocean surface model	Cox-Munk + bio-optical*	Cox-Munk*
Language	Matlab (for development), C++*	Fortran
Speed	Speedup methods required, in study*	Fast

*in development/testing

- Developed formal methodology of investigating sensitivity of intensity and polarization to aerosol properties and aerosol layer altitude (based on Kalashnikova et al., 2011)
- Initial results show that discrimination of absorption is more robust in intensity than polarization

Instrument development, deployment, and testing

- AirMSPI was deployed in PODEX, pre-HyspIRI, and SEAC^{4}RS campaigns in 2013 and pre-HyspIRI in 2014
- Data acquired over AERONET sites and in conjunction with other aircraft instruments (e.g., 4STAR) are being used to evaluate aerosol retrievals
- AirMSPI-2 instrument (currently being built) extends spectral range to include O_2 A-band channel and SWIR bands, with polarization at 1620 and 2185 nm
- In conjunction with sensitivity studies and algorithm development work, this effort is being used to help refine ACE instrument requirements
- See Dave Diner's presentations on instrument technology maturation and AirMSPI results for more information

Aerosol studies for ACE

RSP

Brian Cairns (PI-GISS), Jacek Chowdhary, Matteo Ottaviani,
Bastiaan van Diedenhoven, Mikhail Alexandrov, Andrzej Wasilewski
Snorre Stamnes (LaRC)

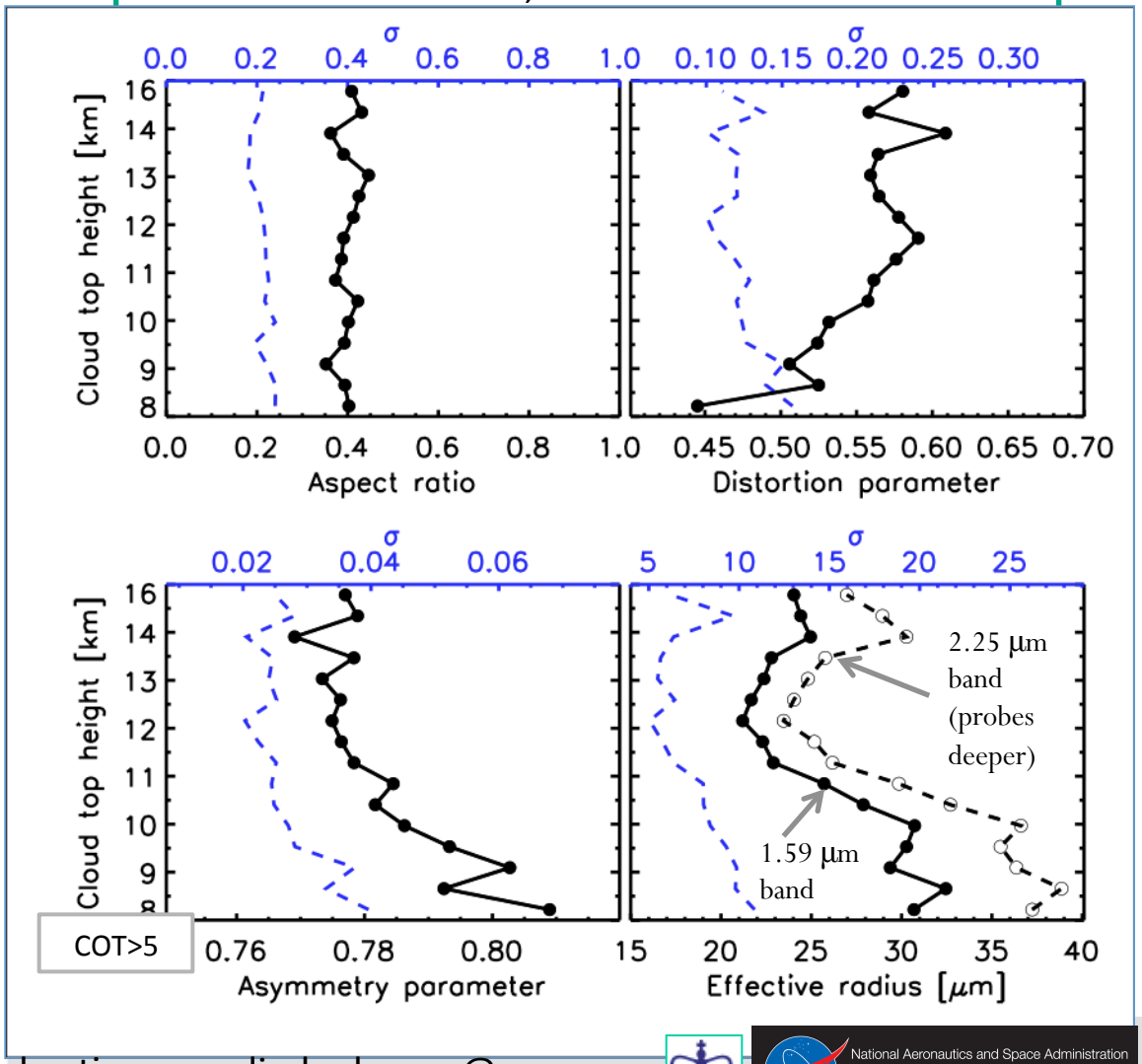
ACE related work at GISS

- Make RT program publically available
  - Clean, streamline, and document the RT program code
  - Comply with Standard Fortran programming language
  - Publish summary of method, validation, and benchmark results
  - Develop user-friendly website for RT results, applications, and updates
- Incorporate RT results for ocean color into GRASP
  - GRASP: Generalized Retrieval of Aerosol and Surface Properties (Dubovik *et al*)
    - Note: ignores polarimetric and bidirectional properties of water-leaving radiance
  - Calculate and incorporate reflection matrices for water-leaving radiance
    - Include variations with wavelength and Chlorophyll a concentrations
    - Variations with ocean surface wind properties are negligibly small
- Comparing in house iterative retrieval with GRASP
  - Developing neural net scheme for fast and accurate first guess
    - Iterative retrieval schemes are required to improve aerosol retrievals, but are slow. Better first guess means fewer iterations.
  - Include aerosol above cloud and cirrus above aerosol in iterative scheme
    - Add ice and water clouds to database of single scattering properties. Water clouds are in many respects a better lower boundary condition than either ocean, or land, because they are bright and aerosol absorption provides a large signal.
    - GRASP can be used for aerosol above cloud retrievals, but not with existing SOS code. Evaluating using vector doubling/adding within GRASP.
- See Brian Cairns' presentation on RSP measurements and analyses

SEAC^{4}RS RSP ice cloud retrieval statistics

- RSP VIS-SWIR multi-directional polarization + reflectance allow retrieval of
  - Cloud top height
  - Cloud optical thickness
  - Ice crystal effective radius
  - Ice crystal aspect ratio
  - Crystal distortion/ roughening
  - Asymmetry parameter
- Retrieval data available in archive
- SEAC^{4}RS statistics reveal
  - Systematic variation among cloud types
  - Variation with top heights
  - Interesting increase in mean R_{eff} near Tropopause

Mean values in **black**, standard deviations in **blue**



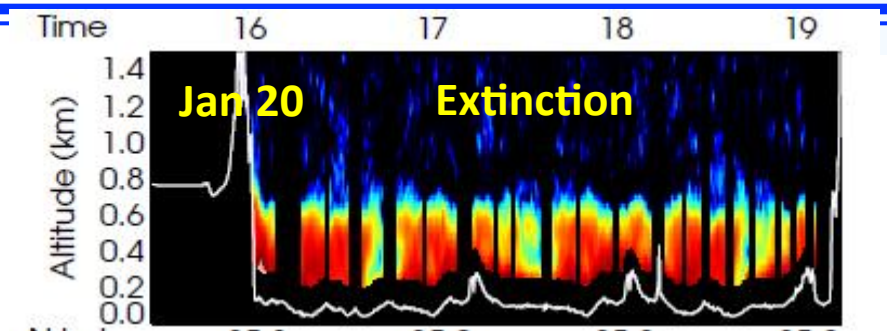
bastiaan.vandiedenhoven@nasa.gov

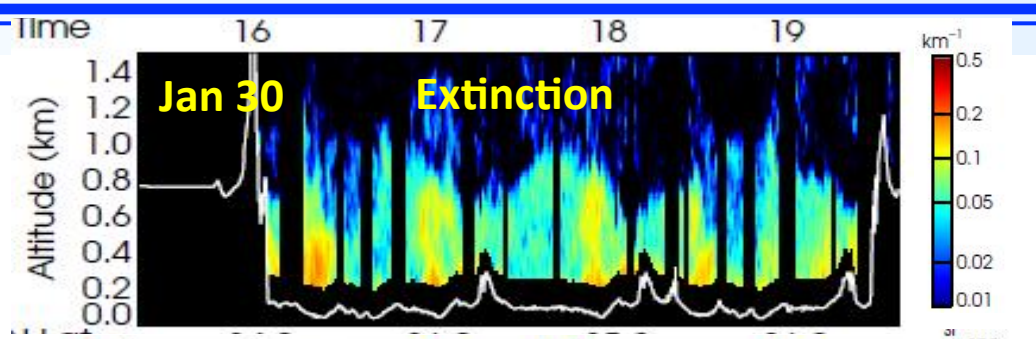
National Aeronautics and Space Administration
Goddard Institute for Space Studies
New York, N.Y. 10025

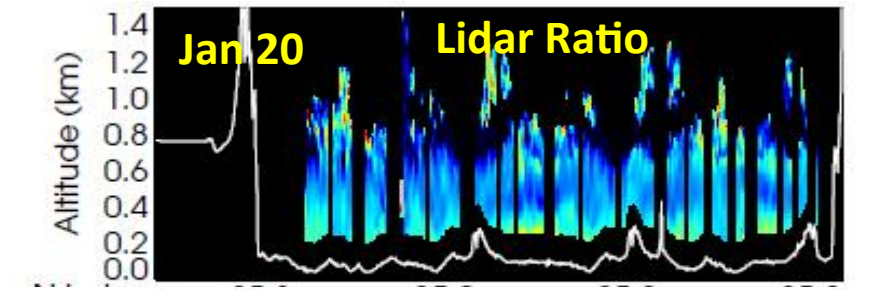
Multiwavelength ("3+2") Aerosol Retrievals from Airborne HSRL-2 during DISCOVER-AQ/PODEX

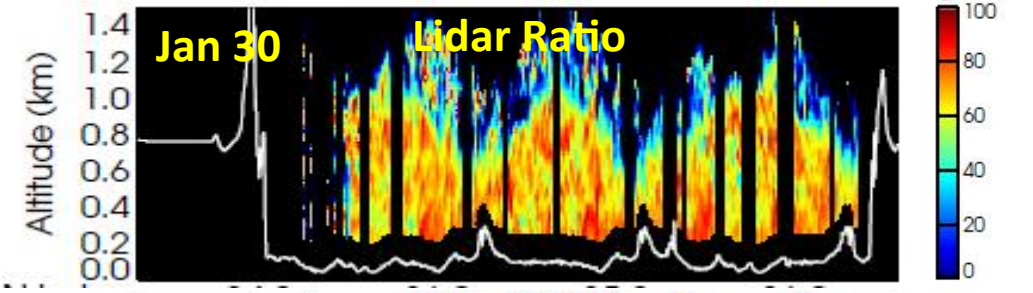
Hostetler, Ferrare, Müller, Hair, Burton
and LaRC HSRL-2 team

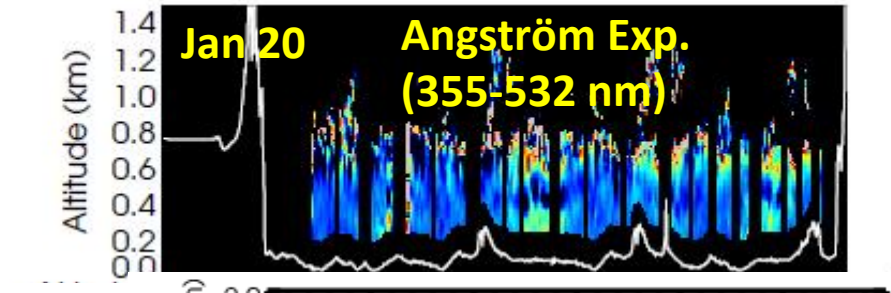
HSRL-2 & AERONET measurements show changes in aerosol properties during two pollution episodes

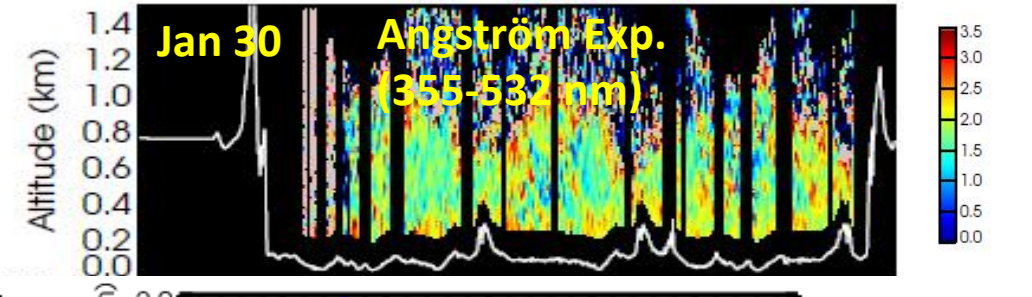


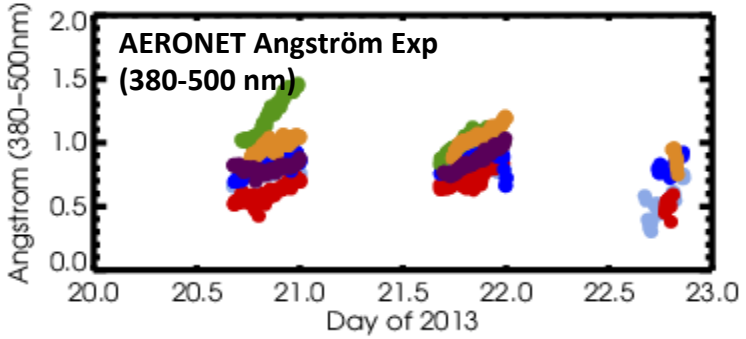


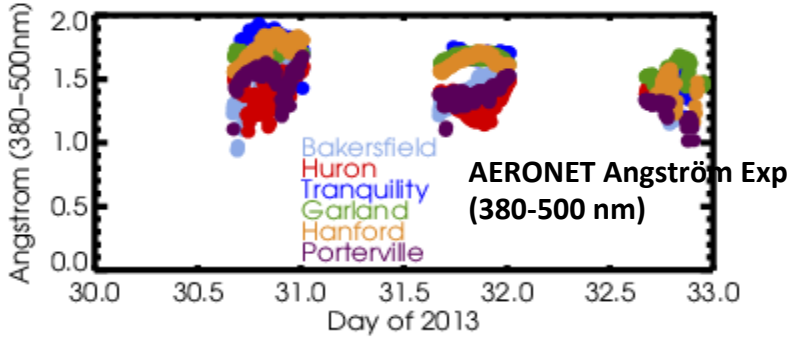






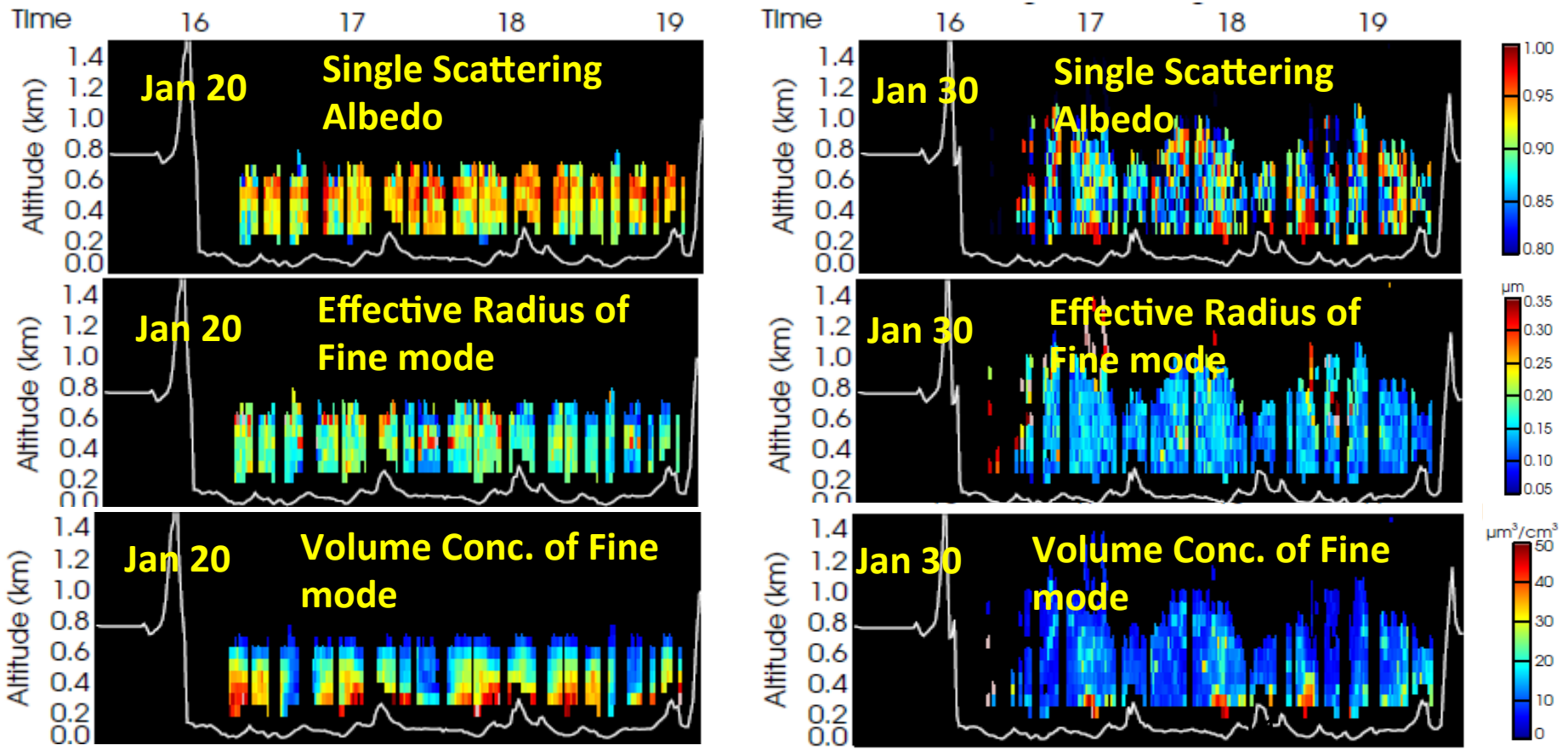






HSRL-2 "3β+2α" retrievals of aerosol properties during two pollution episodes

HSRL-2 measurements of intensive parameters (lidar ratio, Angström Exp.) and parameters derived from multiwavelength "3+2" retrievals indicate that fine mode aerosols during second pollution episode were smaller and more absorbing than during first pollution episode. Airborne in situ measurements also showed the same trend.



Swath Sampling Studies

GISS (Geogdzhayev, Cairns, Mishchenko, Tsigaridis)

GSFC/UMBC (Colarco, Kahn, Levy, Remer)

Satellite AOD Sampling Studies

- Swath width is a design driver for passive optical instruments and has implications for
  - Plume and event monitoring
  - Trend detection and regional AOD and radiative forcing estimation
- Regarding swath width…ACE draft report indicated:
  - Wide swath (i.e. 2 day global coverage) required to identify sources, sinks, and identify aerosol transport (SPTS)
  - Radiative forcing (DARF)…"sufficient spatial and temporal coverage to reduce uncertainties in an unbiased measurement and provide statistics to identify regional and seasonal characteristics of forcing and heating. Narrower swath (~400 km?) adequate for seasonal values averaged over globe and broad regions"
- Comparison of AOD trends in some regions found differences between MODIS and MISR possibly due to sampling differences (Zhang and Reid, 2010)

Satellite AOD Sampling Studies

- Several trade studies investigated the role of sampling on measurements of AOD (e.g. Geogdzhayev et al., 2013, 2014; Colarco et al. 2014)
- Investigations
  - Used a combination of satellite (MODIS) and model data
  - Found that single-pixel width AOT sampling is probably sufficient to resolve global-monthly mean AOT and detect decadal AOT trends at continental scales
  - At regional and seasonal scales, reduced swath produces higher uncertainty in derived AOT and aerosol forcing
- Contextual limitations of the measurement technique limit direct assessments of sampling by other instruments that have greater accuracy and/or fewer gaps – use of aerosol transport models helps resolve these limitations
- Recommendations for future investigations
  - Analyses focused on impact of measurements and measurement requirements for aerosol forcing
  - Address aerosol absorption as well as AOD

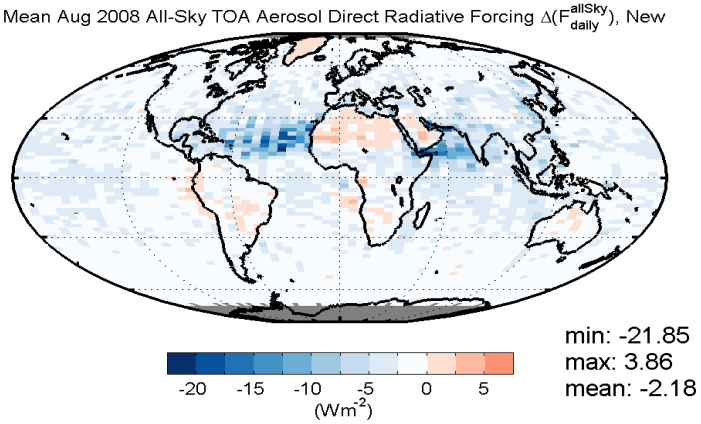
Aerosol Studies for ACE

Dave Winker, Seiji Kato (LaRC)

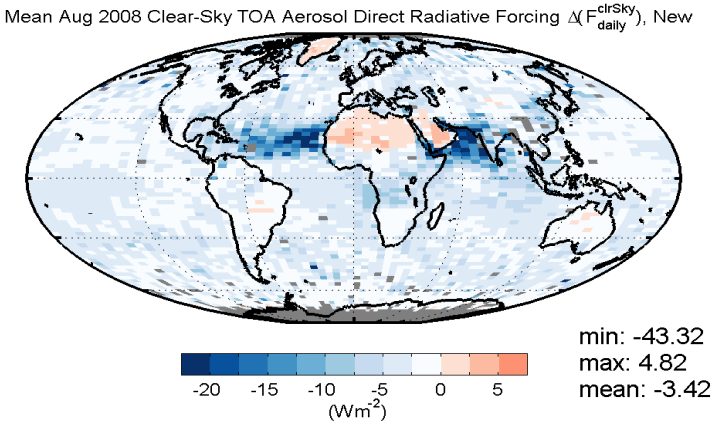
Aerosol Direct Radiative Effect (C3M): Aug 2008

- CALIPSO, CloudSAT, CERES, MODIS (C3M) merged dataset used to examine differences between clear-sky and all-sky aerosol direct radiative effect

All Sky



Clear Sky

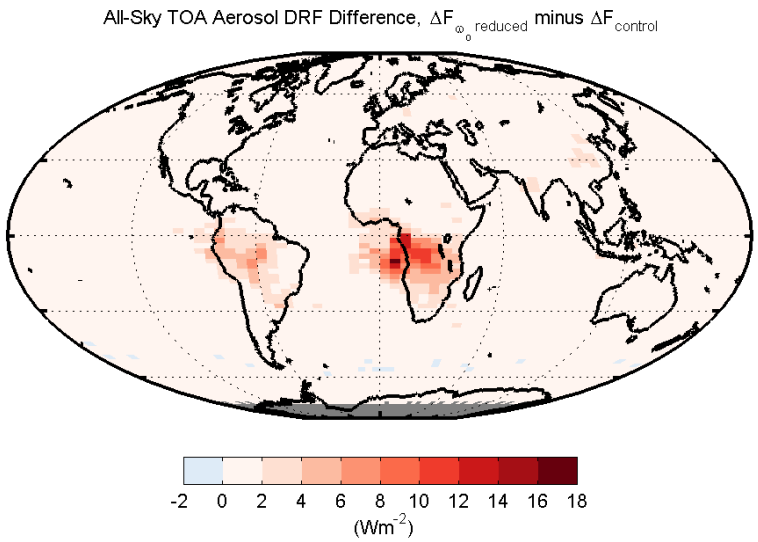


- C3M clear sky direct radiative effect consistent with earlier studies that used NOAA and MODIS algorithms to identify clear skies

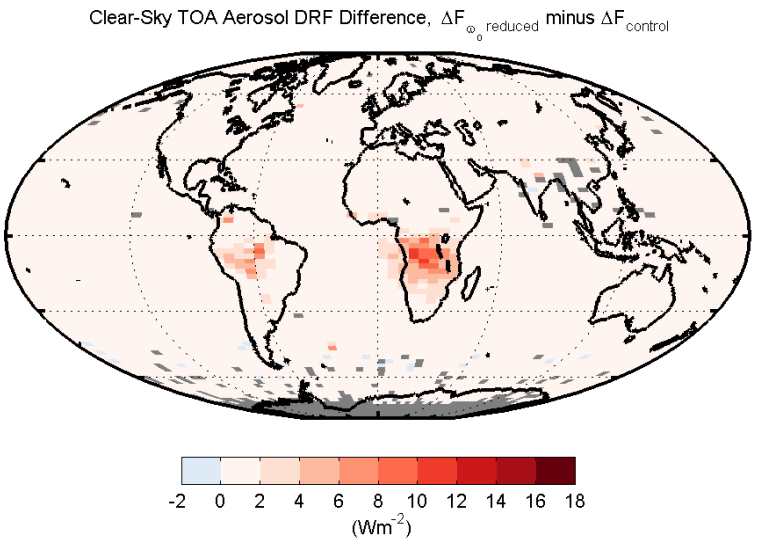
Aerosol Direct Radiative Forcing Sensitivity

- Initial studies are using C3M to evaluate aerosol absorption measurement requirements
- Initial examples shows the difference in DRE (all sky and clear sky) when the SSA of CALIOP identified smoke is reduced by 0.06
- Future activities will pursue
  - Publication describing aerosol direct radiative effect computations
  - Additional aerosol sensitivity studies
  - Sampling studies

All Sky



Clear Sky



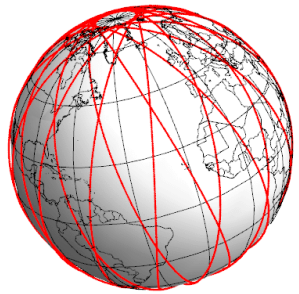
ACE Lidar Aerosol Retrieval Simulation Study

D. N. Whiteman, NASA-GSFC/612, D. Perez-Ramirez, USRA/612
I. Veselovskii, USRA/612, P. Colarco, NASA-GSFC/614

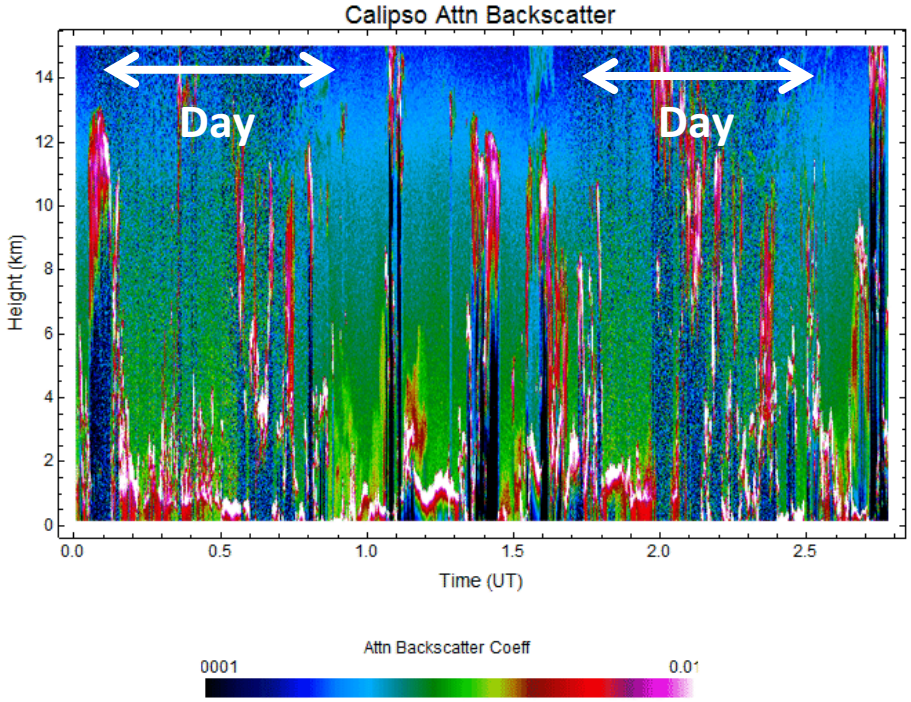
with help and helpful feedback from Steve Palm, Virginie Buchard and LaRC (Rich Ferrare, Chris Hostetler, John Hair, Kathleen Powell, Detlef Müller, Sharon Burton)

ACE Lidar Aerosol Retrieval Simulation Study

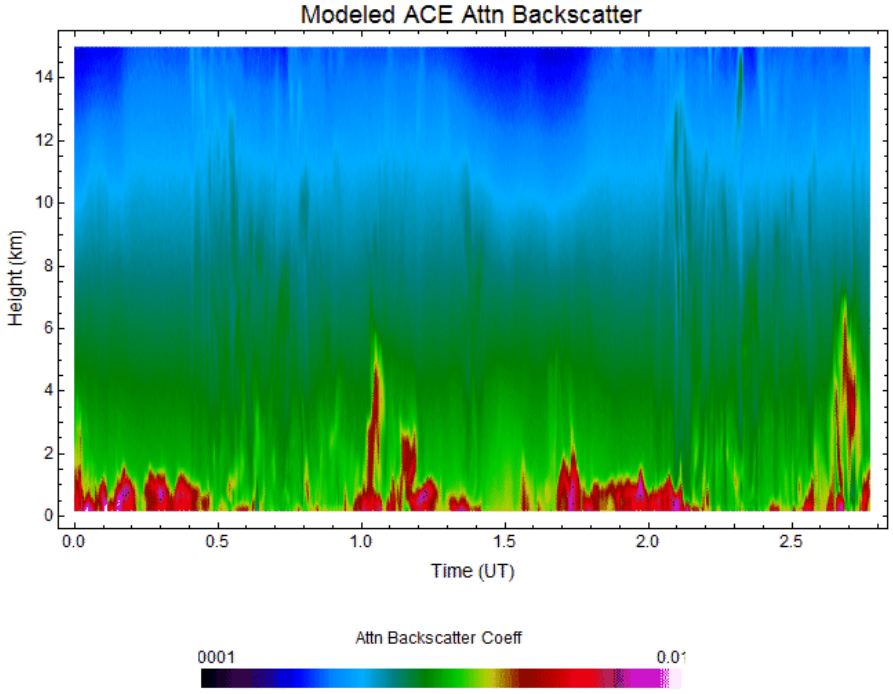
- Simulated multiwavelength HSRL backscatter and extinction profiles using ACE candidate lidar concept and GEOS model atmospheric conditions
- Computed yields for signal levels sufficient for “3+2” and “3+1” aerosol retrievals
- Computed aerosol retrievals for regularization and linear estimation



24-hr Calipso Orbit 7/15/2009



Calipso 532 nm measurements
July 15, 2009



Simulation of same Calipso track using ACE candidate hardware and GEOS atmospheric conditions (*no clouds*)

Results

- For aerosol backscatter and extinction specifications, modeled lidar hardware with different orbit altitudes
  - 450 km - generally meets specifications for both wavelengths
  - 830 km - performance is under study
- Yields for microphysical inversions are being assessed – initial results look promising for fine mode cases
- Additional studies are underway to assess different combinations of wavelengths
- Further studies with different instrument parameters and model input required
- Retrievals of aerosol size distribution and absorption require "3+2" set of backscatter and extinction measurements
- Further studies underway to improve inversions through use of external information

Brief Summary of ACE Aerosol-Related Studies and Activities

- PODEX[1]
  - Aerosol retrieval studies
  - Polarimeter comparisons[2]
- Additional aerosol data acquisition/retrieval studies
  - Passive[3,4,5] (e.g. RSP, AirMSPI in SEAC4RS)
  - Active[6] (e.g. HSRL-2 in DISCOVER-AQ)
- Swath Sampling Studies
- Multiwavelength lidar aerosol retrievals and satellite simulation[6,7]
- Radiative Forcing Studies
- Aerosol Indirect Effect Study
- Aerosol Type Constraints Required for Ocean Color Atmospheric Correction[8]
- Aerosol Data Assimilation[9]
- Aerosol measurements from current and potential future PACE mission as related to ACE science objectives[10]

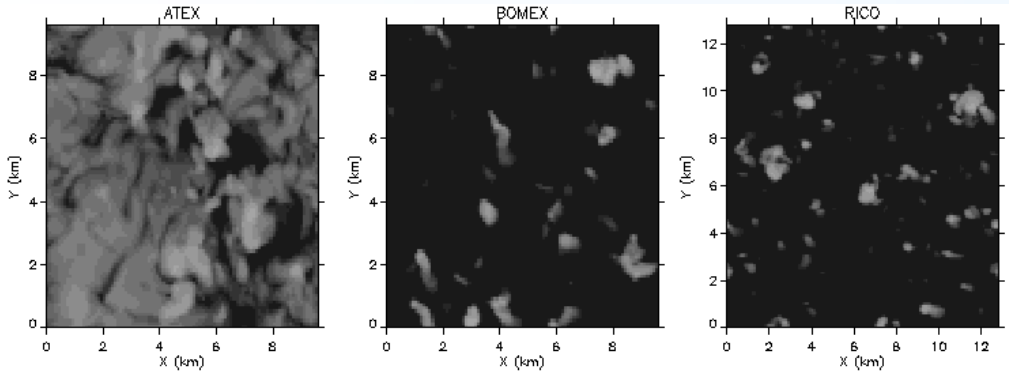
Details in meeting presentations that follow:
[1,10]Ferrare, [2]Knobelspiesse, [3]Cairns, [4]Diner, [5]Martins, [6]Hostetler, Whiteman[7], Kahn[8], daSilva[9]

Extra

Satellite Aerosol Retrieval Parameter Requirements for Studies of Aerosol Indirect Effects

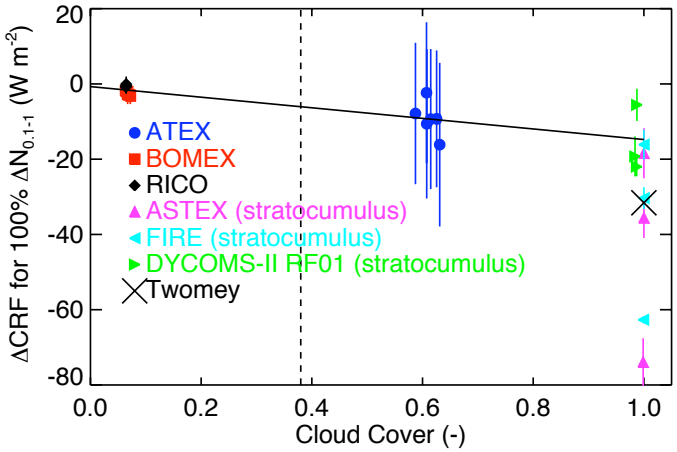
Ann Fridlind and Andy Ackerman

Satellite Aerosol Retrieval Parameter Requirements for Studies of Aerosol Indirect Effects (Fridlind and Ackerman)



➢ **Finding:** global cloud forcing from 100% uncertainty in aerosol number conc. under broken marine clouds translates to 0.7 W m^{-2}, much greater than for proposed uncertainties in effective variance or radius

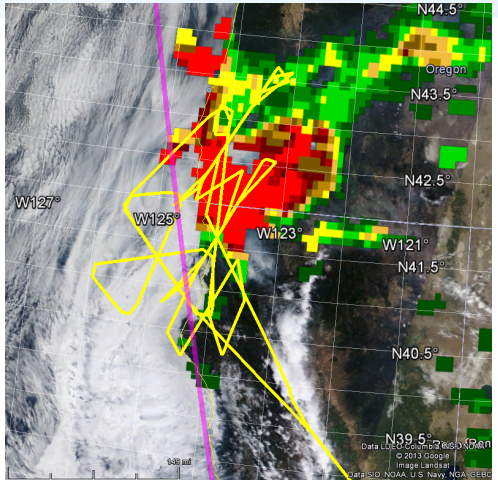
- **Objective:** evaluate proposed aerosol retrieval parameter requirements for ACE satellite mission (number conc. 100%, effective variance 50%, effective radius 10% over 0.1-1 μm radius range)
- **Approach:** evaluate cloud radiative forcing from aerosol changes in LES simulations of three trade cumulus cases



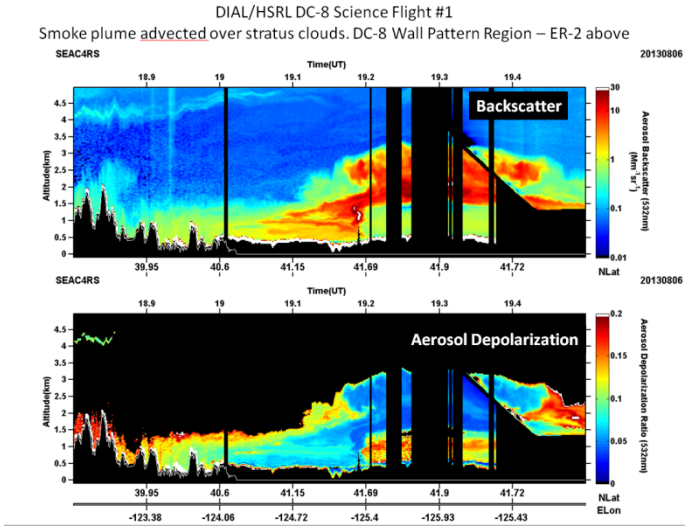
- **Publication**: "Estimating the sensitivity of radiative impacts of shallow, broken marine clouds to boundary layer aerosol size distribution parameter uncertainties for evaluation of satellite retrieval requirements" by Fridlind & Ackerman (*J. Atmos. Ocean. Tech.*, 2011)

PODEX Related Studies Continued During SEAC4RS

- SEAC4RS (Studies of Emissions and Atmospheric Composition, Clouds and Climate Coupling by Regional Surveys) conducted during Aug-Sep 2013 provided:
  - Opportunity to collect these desired conditions with two polarimeters (AirMSPI, RSP) on ER-2
  - Additional aircraft (DC-8, LearJet) to acquire detailed correlative aerosol and cloud measurements
- SEAC4RS provided measurements of targets that were not observed during PODEX:
  - Aerosols (dense smoke) above stratus clouds off Oregon coast
  - Saharan dust along Gulf coast
  - Dense forest fire smoke over land
  - Convective cirrus over Southeastern U.S.



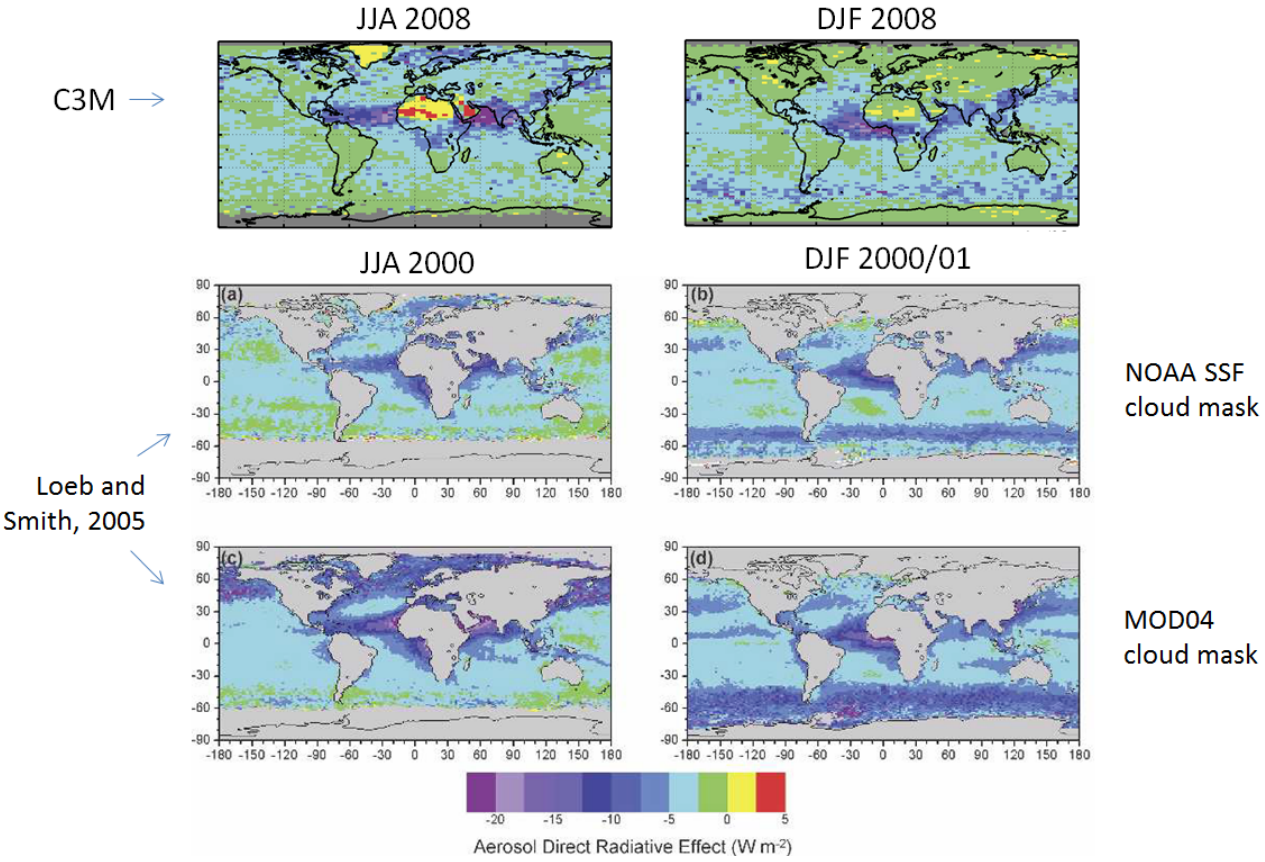
Aqua MODIS imagery at ~21:30 UT on Aug. 6 showing AOT (color), ER-2 track (yellow), and CALIPOS track (purple).



Coincident (preliminary) DIAL/HSRL data from DC-8 showing aerosol backscatter and depolarization measurements of smoke over stratus below ER-2 on August 6 (Hair – LaRC)

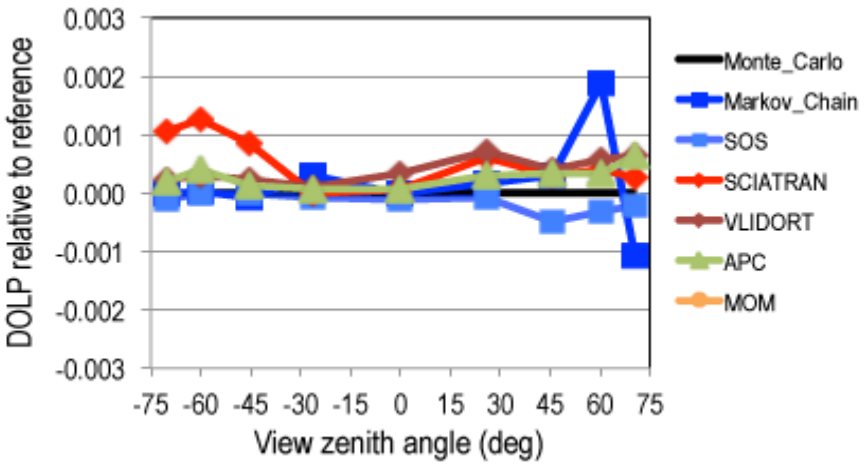
Clear Sky DRE comparison

- C3M clear sky direct radiative effect consistent with earlier studies that used NOAA and MODIS algorithms to identify clear skies



Vector and scalar radiative transfer code intercomparisons

- Comprehensive forward calculations of TOA radiance and, if vector, degree of linear polarization (DOLP) were performed using many different 1D radiative transfer (RT) codes from JPL, LaRC, GSFC, Univ. of Bremen, and RT Solutions to establish the level of model uncertainty.
- A variety of atmosphere and surface types were explored. Participating computational 1D RT techniques
  - Monte Carlo (Reference)
  - Markov Chain + Doubling/Adding
  - Successive Orders of Scattering
  - Matrix Operator
  - Spherical Harmonics
  - Discrete Ordinates

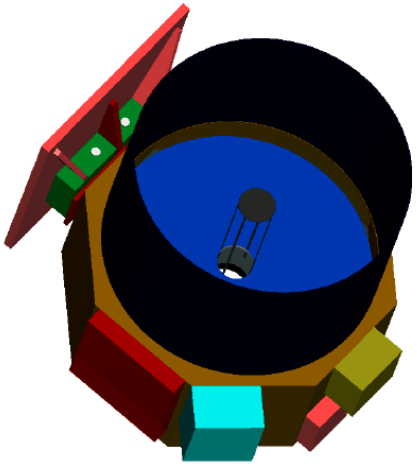


- *Conclusion:* In the most challenging cases, relative to ACE requirement of ±0.005 tolerance in DOLP, RT modeling uncertainty contributes up to ±0.002 error. 1% relative error is achievable in intensity.

Approach

- Simulate multiwavelength Lidar in space
  - Laser: 10 W @ 1064, 532, 5W @ 355, 1.0 m telescope
  - GEOS-5 atmospheric state, VLIDORT scene radiance
  - HSRL lidar with 3 output wavelengths (1064nm, 532nm, 355nm)
  - Both backscatter and molecular measurements ($3\beta+2\alpha$)

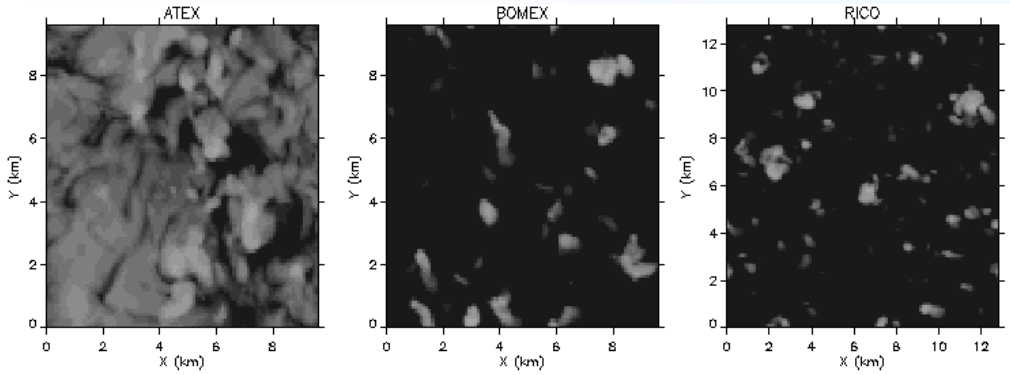
ACE Baseline Concept: *3β+2α+2δ*
High Spectral Resolution Lidar (HSRL)



- Measurements
  - Backscatter at 355, 532, 1064 nm **(3β)**
  - Extinction 355 and 532 nm **(2α)**
  - Depolarization at 2 wavelengths **(2δ)**
  - Goal: ocean surface/subsurface at 532 nm (backscatter and Brillouin scatter)
- Products
  - Lidar-only retrieval of aerosol optical and microphysical properties, cloud optical properties, and aerosol/cloud vertical distribution
  - Lidar + polarimeter retrievals of aerosol optical and microphysical parameters
  - Lidar + radar cloud retrievals
  - Lidar-only retrievals of ocean surface mean square slope (air-sea gas exchange estimates)
  - Lidar-only retrievals of ocean subsurface beam attenuation coefficient

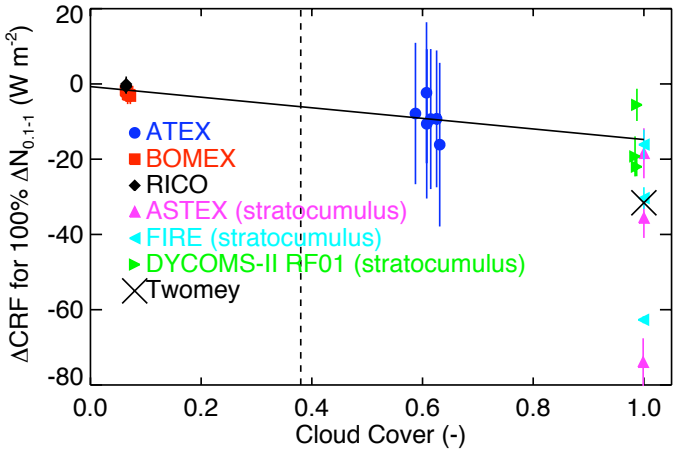
- Model simulates HSRL lidar with 3 backscatter and 2 extinction measurements
- Use these 3+2 (or 3+1) profiles as input to Regularization and Linear Estimation retrievals for aerosol physical properties
- Compare retrieval yields and results for “3+2” and “3+1” extinction levels and uncertainties for aerosol microphysical retrievals
  - α_a (532nm)>20 Mm^{-1}, α_a (355nm)> 50 Mm^{-1}
  - random uncertainty for all signals <15%

Satellite Aerosol Retrieval Parameter Requirements for Studies of Aerosol Indirect Effects (Fridlind and Ackerman)



➢ **Finding:** global cloud forcing from 100% uncertainty in aerosol number conc. under broken marine clouds translates to 0.7 W m^{-2}, much greater than for proposed uncertainties in effective variance or radius

- **Objective:** evaluate proposed aerosol retrieval parameter requirements for ACE satellite mission (number conc. 100%, effective variance 50%, effective radius 10% over 0.1-1 μm radius range)
- **Problem:** no analytic solutions available for cloud albedo changes beyond number concentration (Twomey approximation) or dynamical response
- **Approach:** evaluate cloud radiative forcing from aerosol changes in simulations of trade cumulus



- **Publication**: "Estimating the sensitivity of radiative impacts of shallow, broken marine clouds to boundary layer aerosol size distribution parameter uncertainties for evaluation of satellite retrieval requirements" by Fridlind & Ackerman (*J. Atmos. Ocean. Tech.*, 2011)